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IMAGE ANALYSIS AND MINERALOGICAL STUDIES OF A ROUGHER CONCENTRATE AND A CLEANER TAILING FROM NIOBEC MINES LIMITED

William Petruk

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IMAGE ANALYSIS AND MINERALOGICAL STUDIES OF A ROUGHER CONCENTRATE AND A CLEANER TAILING FROM NIOBEC MINES LIMITED

by

W. Petruk

ABSTRACT

Two samples from the Niobec concentrator were studied with the SEM-IPS-IAS image analysis system at CANMET to find the reason for the high loss of niobium to the tailing. The rougher concentrate was studied to identify the pyrochlore varieties in the ore, and the cleaner tailing was studied to determine the mode of occurrence of the niobium-bearing minerals in the tailing. The main variety of pyrochlore in the ore is a Na pyrochlore and it occurs in well-developed grains. Other varieties are Fe pychlore, Sr pyrochlore and a Ti pyrochlore. These varieties tend to occur as porous grains and appear to replace the Na pyrochlore.

The main niobium-bearing minerals in the tailing are pyrochlore and columbite, a minor one is rutile. 85% of the columbite is in relatively large free or nearly free grains, and 65% of the pyrochlore is in small free or nearly free grains. It is estimated that at least 50% of the niobium in the tailing is recoverable without regrinding, and about 15% is non-recoverable.

INTRODUCTION

A request to conduct an image analysis study on mill products from the Niobec concentrator with the SEM-IPS image analysis system (SEM-IPS-IAS) at CANMET was received from R. Biss of Niobec, Les Services TMG Inc., St. Honore, Cte Dubuc, Quebec, G0V 1L0 in December, 1984. Mr. Biss stated tht they have a high loss of niobium to the tailings from the concentrator and have been unable to develop a satisfactory p ocess for reducing this loss. In order to design an appropriate process they need to know the mineral varieties, liberations, textures and sizes of a statistically valid number of the niobium bearing grains in the tailing. Such information can best be determined with an image analysis system that can automatically find mineral grains in polished sections on the basis of their compositions, and then perform image analyses which are appropriate to mineral beneficiation. An appropriate image analysis investigation must include a determination of the liberation characteristics of the minerals. At the present time the SEM-IPS-IAS at CANMET is the only image analysis system in Canada that has the capability of performing such an analysis.

The SEM-IPS-IAS at CANMET is, in essence, a prototype of a complex image analysis system and all of its capabilities are not yet developed. Prior to the request from Niobec the nondeveloped capabilities included the program for automatically finding grains on the basis of their composition and performing image analysis on the grains. This "niobec project" provided the impetus to develop the program, which was completed in July, 1985. The image analysis study of the concentrate and tailings was subsequently performed as a carry-over of the S.T.A.R.T. program.

SAMPLES

The samples received consisted of a few grams of rougher concentrate and several hundred grams of pyrochlore cleaner tailing. Mr. Biss reported the composition of a Na pyrochlore, Fe pyrochlore, columbite and rutile in the concentrate (Table 1), and an assay for the tailing (Table 2).

METHOD OF INVESTIGATION

The concentrate was screened into +74, 74-37 and -37 micrometer fractions, and the tailing into -147, 147-74, 74-37, 37-26 and -26 micrometer fractions. Polished sections were prepared from each screened fraction but there was not enough material for a polished section of the -37 µm fraction of the concentrate. The polished section of the 74-37 µm fraction was studied with the SEM-EDXA to identify the minerals on the basis of elements present and to semi-quantitatively determine their compositions.

Polished sections of sized fractions of the concentrate were analysed with the SEM-IPS-IAS by first collecting a baskscattered image (SEM-BSE) with the SEM. The image was then automatically transferred to the image analyser and each grey level in the image was correlated to an identified mineral. The grey levels were detected separately and every grain was analysed automatically. The analysis included determining the mineral quantities, liberations and size distributions.

The tailing sample contains a number of minerals that in the SEM-BSE image have similar grey levels to those of pyrochlore and columbite. Therefore, to automatically find the pyrochlore and columbite grains in the tailing it is necessary to determine the composition of each particle. This was performed automatically with the SEM-IPS-IAS by (1) detecting the grey level which includes the grey level for pyrochlore and columbite, (2) automatically identifying each particle on the basis of its chemical composition by using a mineral-chemistry file, (3) isolating the identified columbite and pyrochlore grains, and (4) analysing the selected grains to determine the quantities, liberations, and size distributions.

CONCENTRATE

MINERALOGY

The main mineral in the concentrate is pyrochlore, minor ones are columbite, zircon, rutile, barite and apatite. The mineral quantities, in area % of polished sections, were determine for the +74 and 74-37 µm fractions with the image analyser, and the mineral quantities in the concentrate were calculated by combining the data for the +74 and

74-37 μm fractions (Table 3). The -37 μm fraction represents only 1.3 wt % of the concentrate therefore it was disregarded in the calculations.

Several compositional varieties of pyrochlore are present. They occur both as intergrowths with other pyrochlore varieties and as separate grains (Fig. 1). The most common variety is a Na pyrochlore that contains small amounts of Fe and Ti (Table 4). Most of it occurs in well developed grains, but some is present as twins with other pyrochlore varieties (Fig. 3 and 4). A minor amount of the Na pyrochlore contains small amounts of thorium; the Th variety is lighter grey than the Na pyrochlore on the SEM-BSE image. In Figure 1 the medium grey zone in the central part of the particle that has analysis spot 6, and the zone containing analysis spot 4 is enriched in thorium.

A second pyrchlore variety is slightly enriched in titanium (Table 4); it will be referred to in this report as Ti pyrochlore. It is intergrown with the Na pyrochlore both as twins (Fig. 1 and 2) and as replacements (Fig. 3 and 4). The Ti pyrochlore in the replacement zone tends to be porous.

Another pyrochlore variety contains strontium and small amounts of thorium; it will be referred to in this report as Sr pyrochlore (Table 4). This mineral occurs as borders on Ti pyrochlore (Fig. 3 and 4), as replacements of the thorium-bearing Na pyrochlore (Fig. 1 - grain with analysis spots 1 and 4), and as separate grains.

The final pyrochlore variety observed in the samples is an Fe pyrochlore. The iron replaces calcium, and grains wth both relatively low and relatively high iron contents have been found. The particles of this pyrochlore variety are extremely porous (Fig. 1 - spot 5, and Fig. 5). Some particles contain only the Fe pyrochlore, whereas others have a complex intergrowth of both the Fe and Na varieties (Fig. 5).

The other main Nb-bearing mineral is columbite. It generally occurs as small inclusions in Na pyrochlore (Fig. 6), as small remnants in Ti and Sr pyrochlores (Fig. 3 and 1), and as small separate grains. The columbite inclusions in the Na pyrochlore commonly occur in clusters which are generally aligned to form psuedoveins. In some cases the ore breaks along these psuedoveins to produce Na pyrochlore particles partly bordered by columbite (Fig. 7).

The rutile contains some niobium (Table 4); only free rutile grains were observed in the concentrate.

LIBERATIONS AND SIZE DISTRIBUTIONS

The +74 and 74-37 mesh fractions of the concentrate were analysed to determine the quantities and liberation characteristics of the pyrochlore varieties, of pyrochlore grains composed of all pyrochlore varieties, and of columbite. Data for mineral quantities are given in Table 3. The analysis for mineral liberations involved determining the percentage of each mineral in a particle, total area of the particle, and the area of mineral in the particle. The particles were classified as those containing 0-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90, and 90-100 area % of the mineral. Particles containing 90-100 area % of a mineral are considered to be free grains. The data for the mineral grains in each fraction are reported in Table 5 as proportion of mineral, on the basis of area %, that is present in each class of particle. The data for each fraction were combined and are shown graphically as liberation characteristics for the mineral in the concentrate (Fig. 8).

The grains analysed as Fe pyrochlore could not be readily discriminated in the SEM-BSE image from the Ti pyrochlore and from the thorium-bearing Na pyrochlore. Therefore, the Fe pyrochlore, Ti pyrochlore, and thorium-bearing Na pyrochlore were combined and analysed together as Fe pyrochlore.

The liberation characteristics for the minerals, shown in the graphs of Figure 8, reflect the textures described above (see Fig. 1 to 7). A large amount (about 30%) of the Na pyrochlore is in free particles, with much of the remainder being in particles that contain significant amounts of the Na pyrochlore. The "Fe pyrochlore" is present largely in composite particles but many of the particles contain significant amounts of the "Fe pyrochlore" variety. The Sr pyrochlore occurs largely in composite particles that contain about one-half Sr pyrochlore and one-half other pyrochlore varieties. Since the pyrochlore varieties are intergrown and occur in large pyrochlore grains, the liberation characteristics show that most of the pyrochlore (composed of all pyrochlore varieties) occurs in the concentrate as free grains. By contrast the columbite occurs largely as inclusions in pyrochlore; therefore, it is present largely in grains that contain small amounts of columbite. A small percentage of the columbite is present as free grains.

TAILING

The pyrochlore in the tailing was not subdivided into varieties, because of lack of experience in automatically identifying sub-species of a mineral occurring as very small grains. After the analysis was completed, Mr. Biss and Dr. G. Barberry of Laval University visited the CANMET laboratory to gain an appreciation of the capabilities of the SEM-IPS-IAS, and to discuss the problem of niobium in the tailing. Mr. Biss stated that it is significant to determine the proportion of Fe pyrochlore in the tailings, and to determine whether the Fe pyrochlore occurs as borders on other pyrochlore varieties. Perhaps such a study can be undertaken at a later date.

The quantities and distributions of pyrochlore, columbite and of minerals with a high atomic number were determined with the image analysis system (Table 6). Minerals having a high atomic number include apatite, rutile, zircon, hematite, pyrite, sphalerite, pyrochlore, columbite, and a rare earth mineral which contains Ce, Nd and Ca. The quantities of pyrochlore and columbite in the sized fractions were combined, using the weights of each fraction, to determine the quantities, in area %, of the minerals in the tailings. It was calculated that the pyrochlore plus columbite in the tailings contain 1.54 wt % Nb_2O_5 by assuming specific gravities of 5.0 for the pyrochlore and columbite and of 3.0 for the tailing. This value compares well with the assay value of 1.62 (Table 2); particularly since the rutile contains some niobium.

The mineral distributions (Table 6) show that one-half of the pyrochlore is in the -500 mesh fraction, whereas 61% of the columbite is in the 100-500 mesh portion of the tailing.

The relative proportions, in area % of pyrochlore and columbite occurring as free grains (90-100% class), and as inclusions in particles that contain various amounts of the mineral in question are given in Table 7 and shown graphically for each fraction in Fig. 9 and 10. The data for the screened fractions were combined and are shown graphically in Fig. 11. It has been observed in investigations of base metal ores that particles containing more than 70% of the mineral behave as free grains. Figures 9-11 show that all fractions contain both free and unliberated pyrochlore and columbite, but much of the columbite is in free or nearly free grains,

whereas a large proportion of the pyrochlore occurs as inclusions in particles that contain less than 70 area % pyrochlore. This is particularly evident in the summary graphs shown in Fig. 11.

Size distributions were determined for the pyrochlore and columbite grains. Results for all grains, without distinguishing whether they are free or unliberated, are given in Table 9 and shown graphically for the combined data in Fig. 12. Figure 12 shows that most of the columbite is between 18.5 and 74 micrometres in diameter, whereas most of the pyrochlore is in grains smaller than 18.5 micrometres.

Figures 13-17 are graphs which show the relationship between the sizes of pyrochlore and columbite grains that occur as inclusions in particles and the quantity, in area %, that these grians contribute to the host particles. When the grains contribute 100% they are free grains. All the graphs show that the free pyrochlore and free columbite grains are of all sizes, but every fraction contains a higher percentage of free columbite grains than of free pyrochlore grains. Furthermore every screened fraction contains a large number of very small pyrochlore grains. These grains occur as inclusions in gangue particles which contain less than 20 area % pyrochlore.

CONCLUSIONS

The investigation has shown that most of the niobium in the tailing occurs in pyrochlore and columbite, with a small amount in rutile. It was determined by image analysis that the tailing contains 1.2 wt % pyrochlore and 1.0 wt % columbite, and was estimated to contain about 1 wt % rutile. These data indicate that about 50% of the niobium is in pyrochlore, 43% in columbite, and 7% in the rutile.

It was determined that 85% of the columbite is in free or nearly free grains (more than 70% columbite in particles), and that most of the grains range from 18.5 to 74 micrometres in diameter. By contrast, 65% of the pyrochlore is in free or nearly free grains, but most are smaller than the columbite grains. If it were assumed that 90% of the free or nearly free columbite and 60% of the free or nearly free pyrochlore can be recovered, about 50% of the niobium in the tailing can be recovered without regrinding.

Table 7 shows that 8.6% of the pyrochlore and 2.4% of the columbite occur as very minute grains in gangue particles and compose less than 20 area % of the particles. These grains account for 5.7% of the niobium in the tailing and are unrecoverable. It is noteworthy that the estimated 7% of niobium in rutile is also unrecoverable.

It was found that 26.9% of the pyrochlore and 11.8% of the columbite occur as inclusions that compose 20 to 70 area % of the gangue particles. These grains account for about 20% of the niobium in the tailing. It is possible that some could be recovered if the tailing was reground.

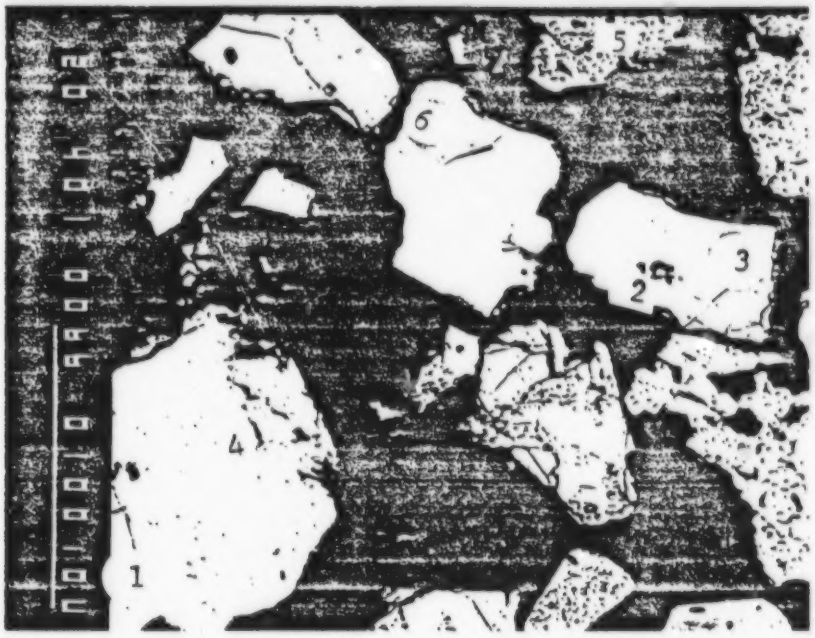


Fig. 1. SEM-BSE image of polished section of rougher concentrate showing the various pyrochlore grains. Spots 3 and 6 and other dark grey grains are Na pyrochlore; spot 2 is on a grain of Ti pyrochlore, spot 4 is Th-bearing Na pyrochlore, spot 1 is on a grain of Sr pyrochlore, and spot 5 on porous Fe pyrochlore. The scale bar is 100 μm.

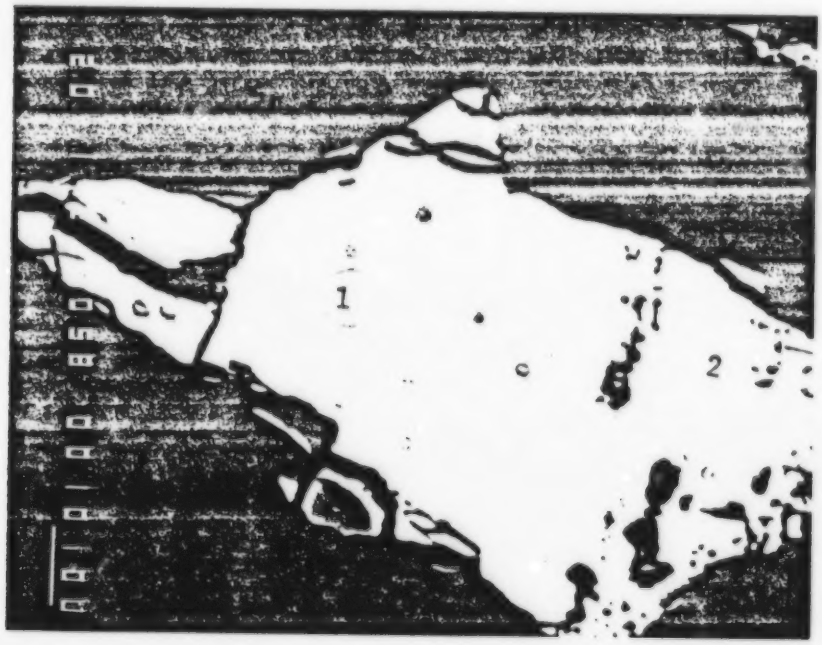


Fig. 2. A grain containing a zone of Na pyrochlore (grey) and of Ti pyrochlore (white). The scale bar is 10 μm.

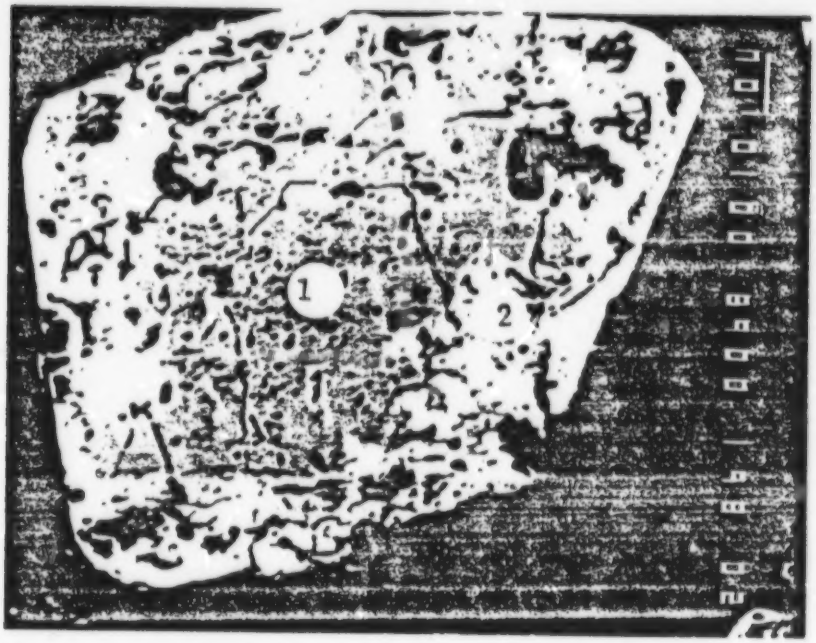


Fig. 3. An SEM-BSE photograph of a complex pyrochlore gran. It contains a Na pyrochlore at the centre (dark grey) which is surrounded by a Ti pyrochlore (grey). The Ti pyrochlore is in turn partly bordered by a narrow rim of Sr pyrochlore (white). The white inclusions near the bottom-right part of the photograph are columbite. The Sr pyrochlore appear to replace the Na pyrochlore. The scale bar is 10 μm.

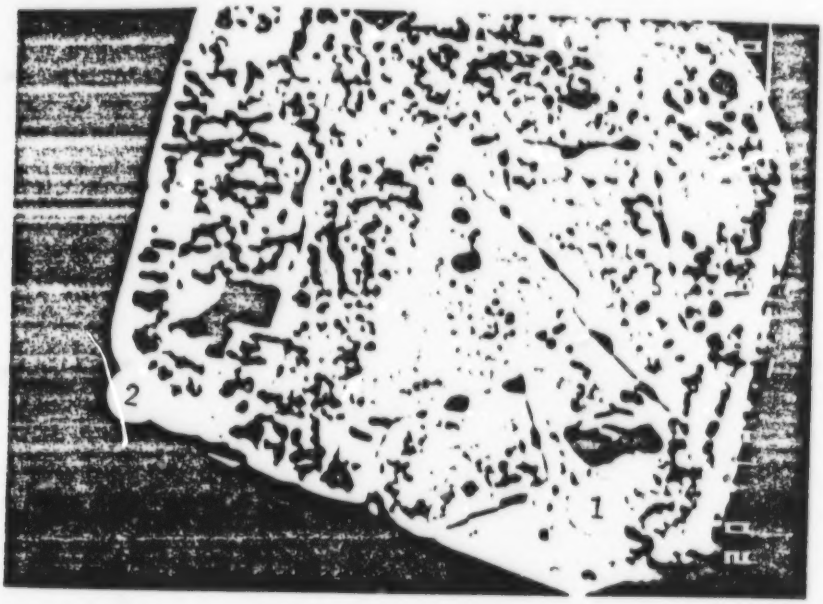


Fig. 4. Complex pyrochlore grain composed of Na pyrochlore at the centre (dark grey) which is largely replaced by Ti pyrochlore. The Ti pyrochlore is bordered by Sr pyrochlore and contains numerous small inclusions of columbite. The scale bar is 10 μm.

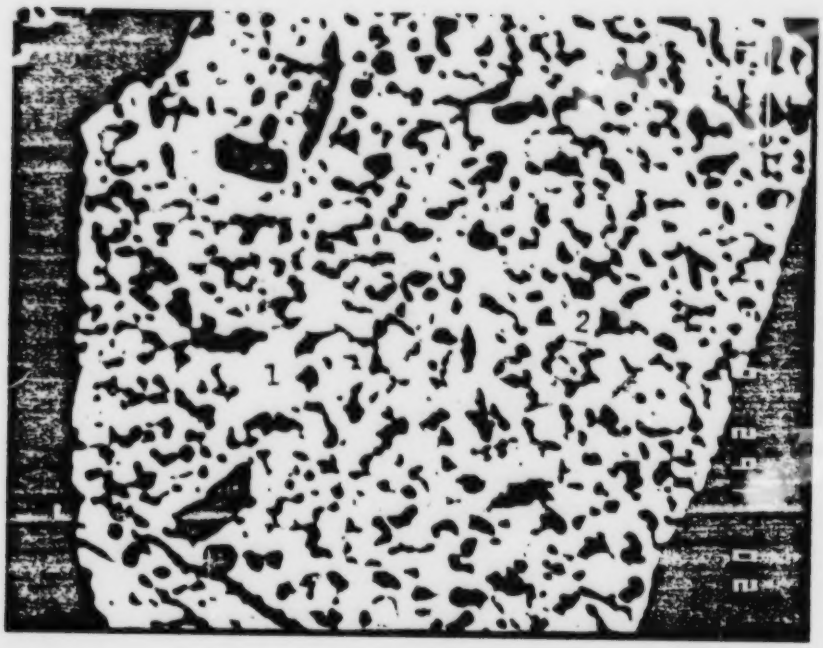


Fig. 5. A porous grain composed of Fe pyrochlore (white) intergrown with Na pyrochlore (grey). The scale bar is 10 μm.

Fig. 6. Columbite inclusions (white) in Na pyrochlore. The scale bar is 10 μm.

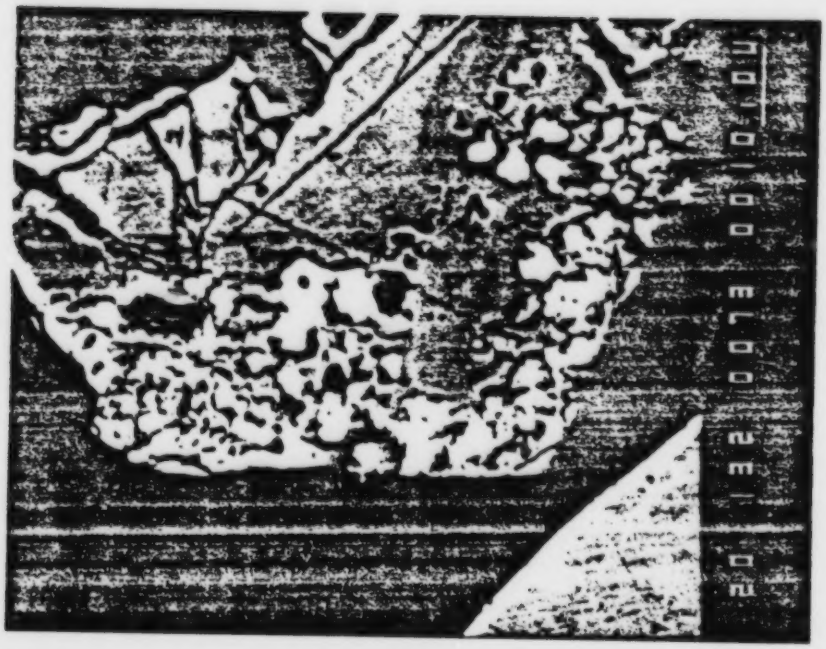


Fig. 7. Columbite grains (white) along the edge of a Na pyrochlore particle. The scale bar is 10 μm.

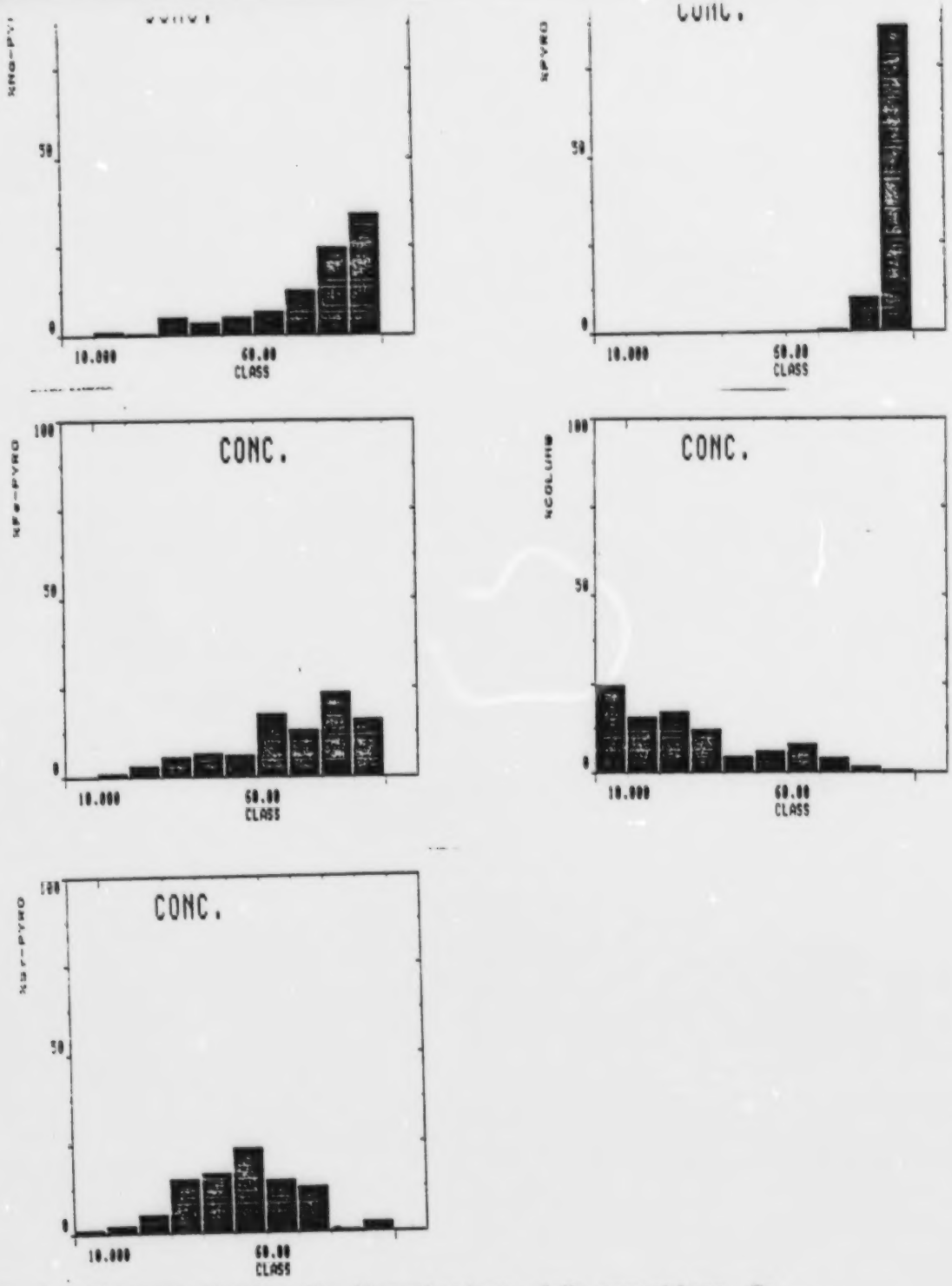


Fig. 8. Diagrams showing the distributions of Na pyrochlore, Fe pyrochlore, Sr pyrochlore, combined pyrochlores and columbite in particles that contain various percentages (class) of each mineral in the rougher concentrate.

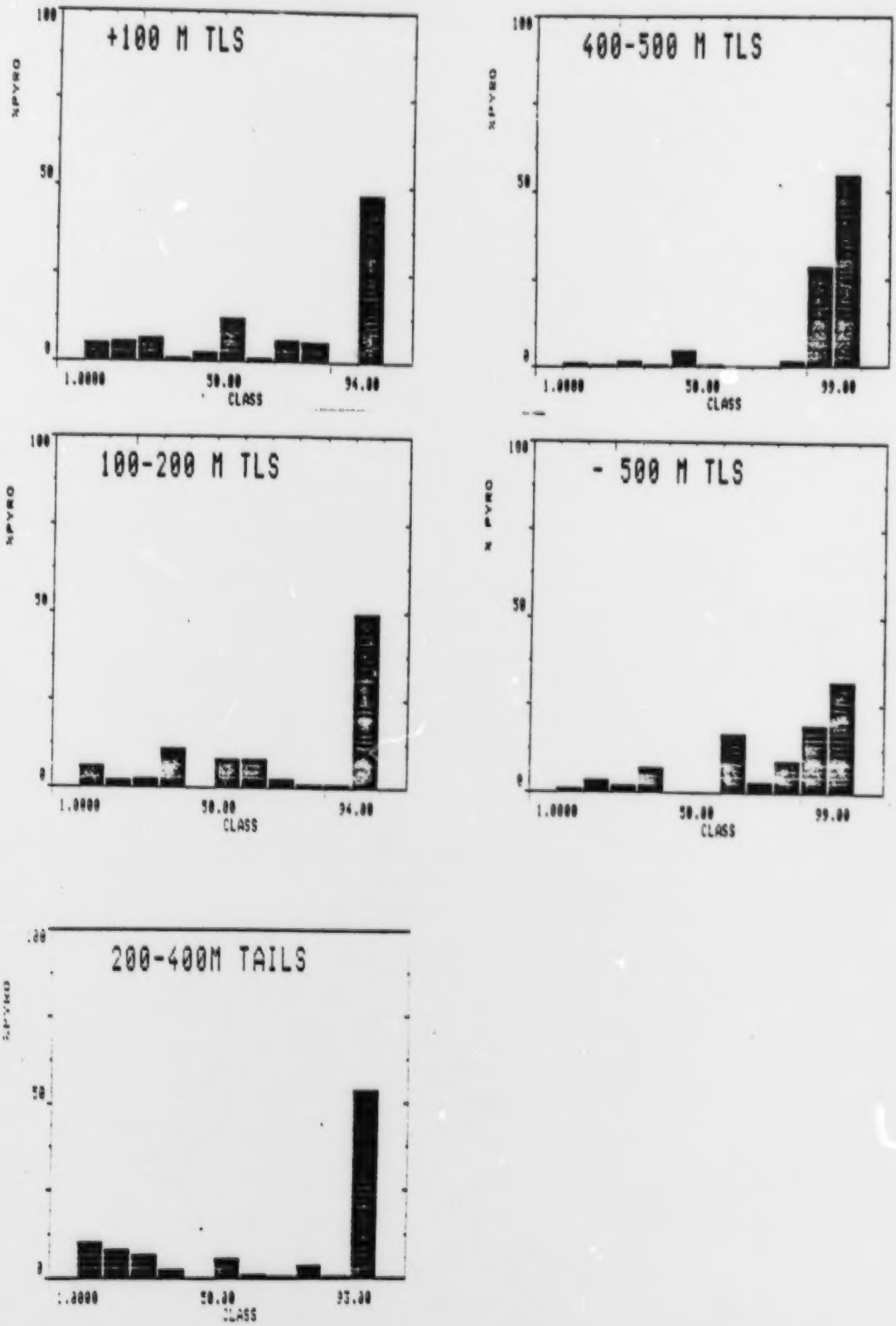


Fig. 9. Diagrams showing the distributions of pyrochlore in particles that contain various amounts of the mineral (class) screened fractions of the cleaner tailing.

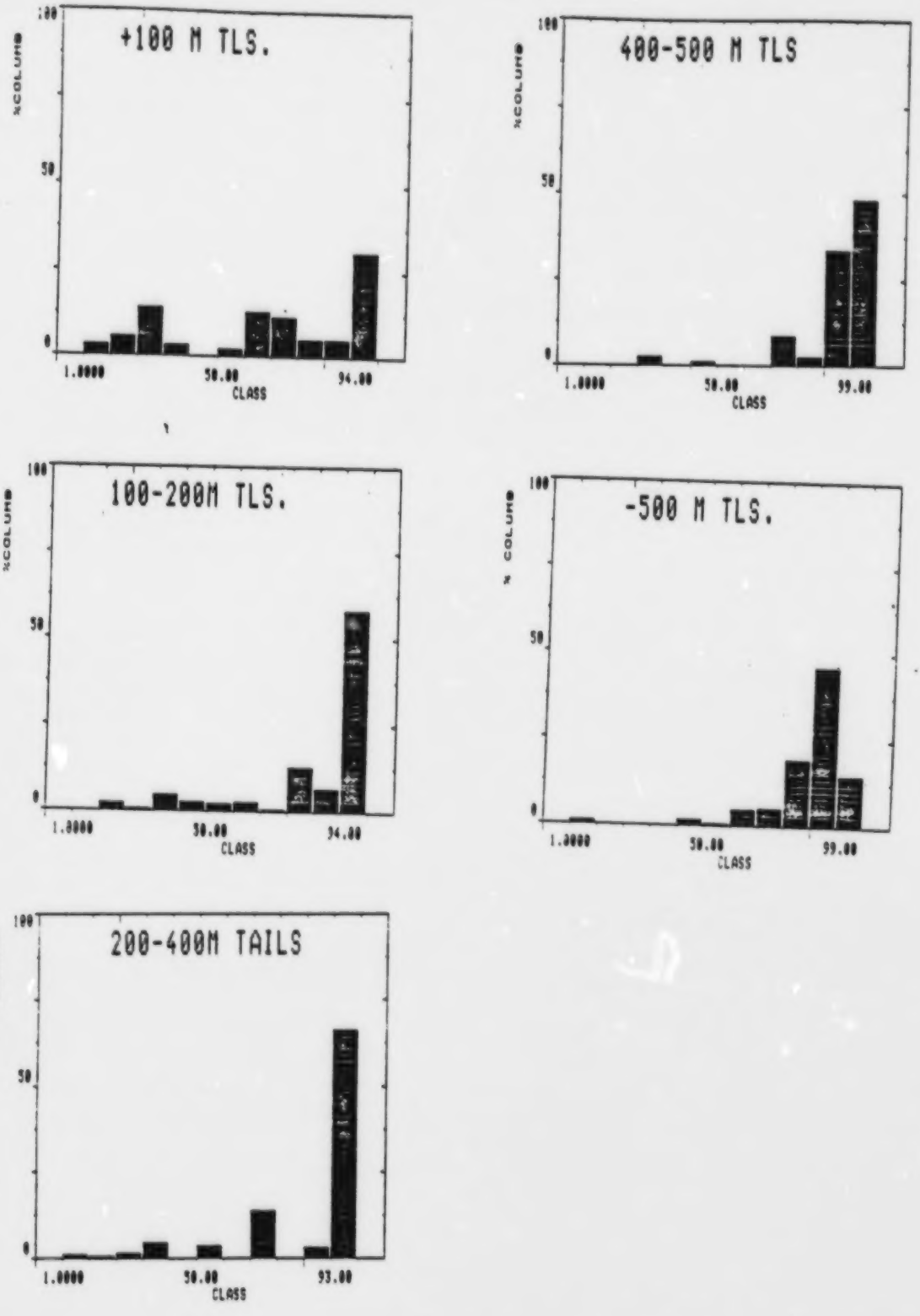


Fig. 10. Diagrams showing the distributions of the columbite in particles that contain various amounts of the mineral (class) in screened fractions of the tailing.

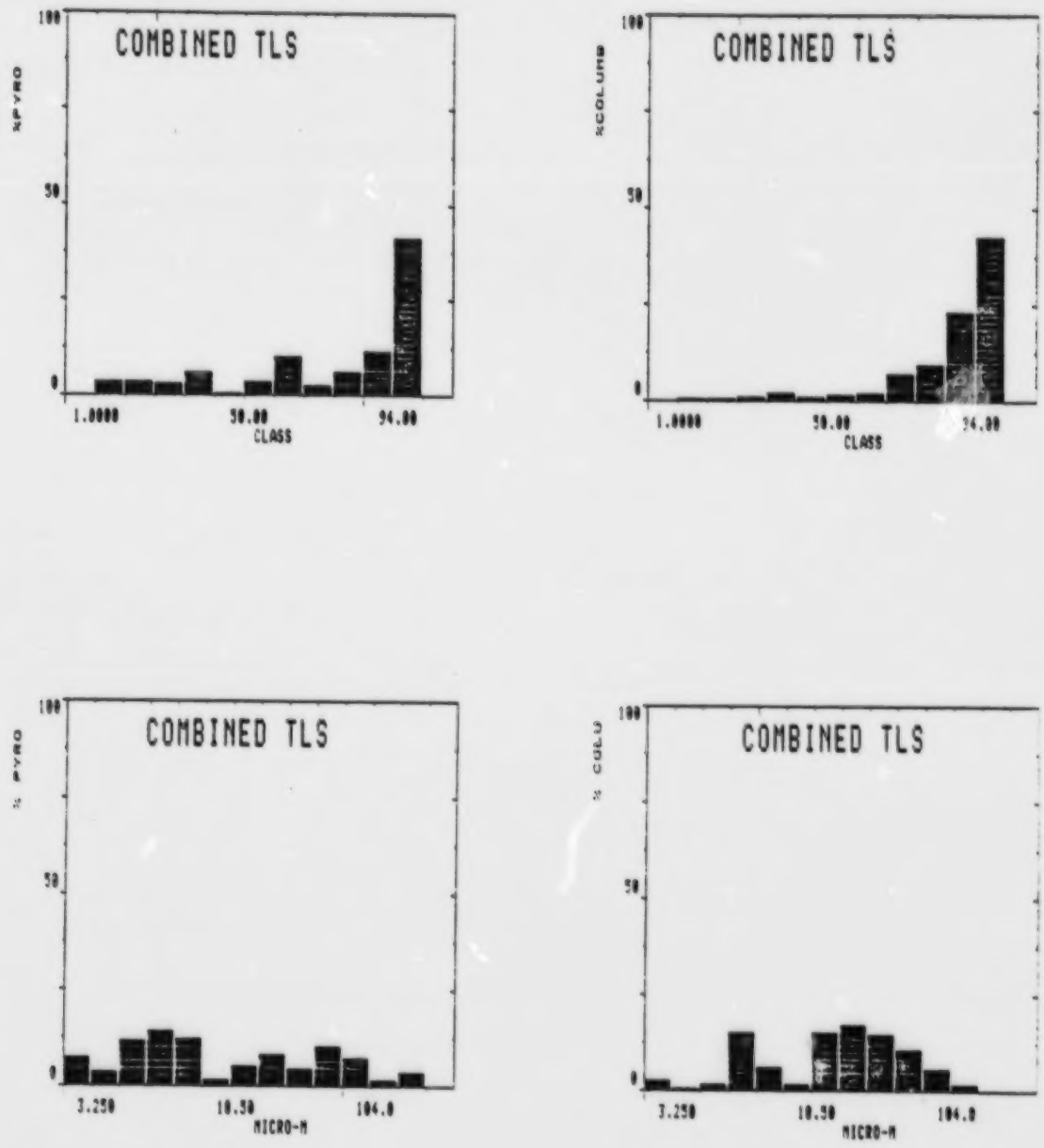


Fig. 11. The two top diagrams show various amounts of pyrochlore and columbite in particles that contain different amounts of the minerals (class) in the tailing sample, and the bottom two diagrams show the size distributions of the same pyrochlore and columbite grains.

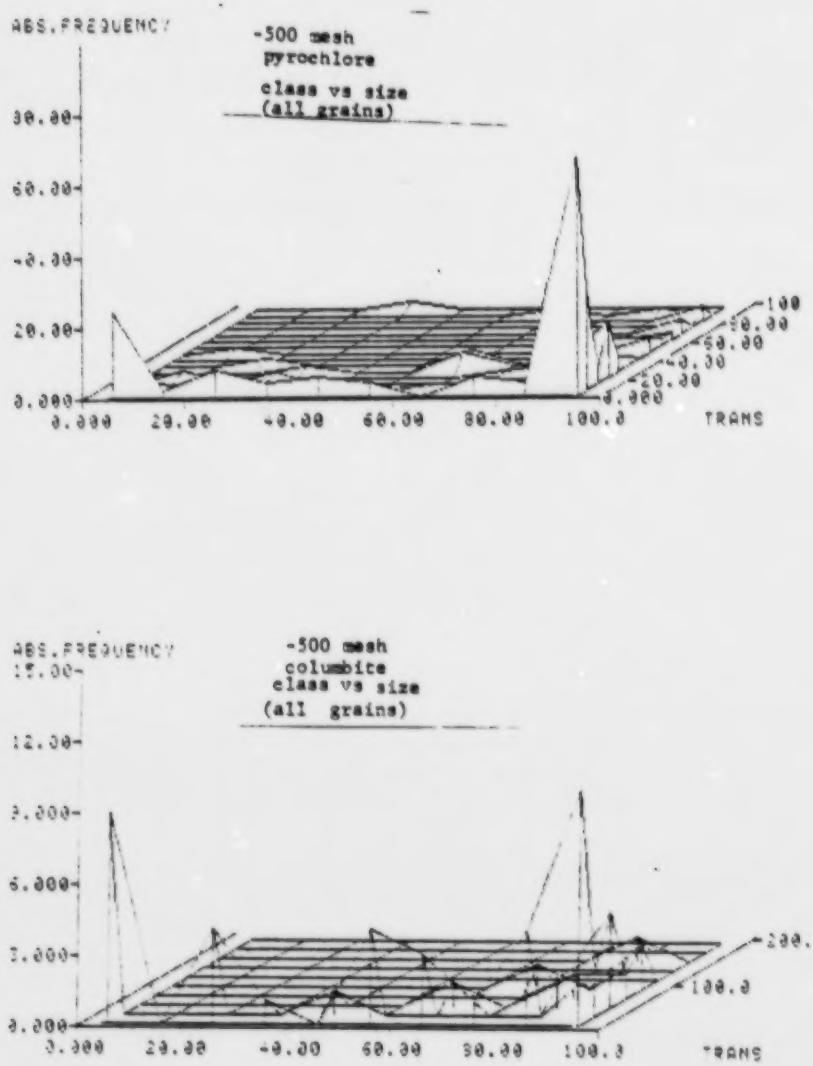


Fig. 12. Three dimensional diagrams for pyrochlore (top diagram) and columbite (bottom diagram) in the -500 mesh fraction of the tailing showing the relationships between these minerals in particles that contain various amounts of the minerals (trans) and the sizes of the pyrochlore and columbite in these grains.

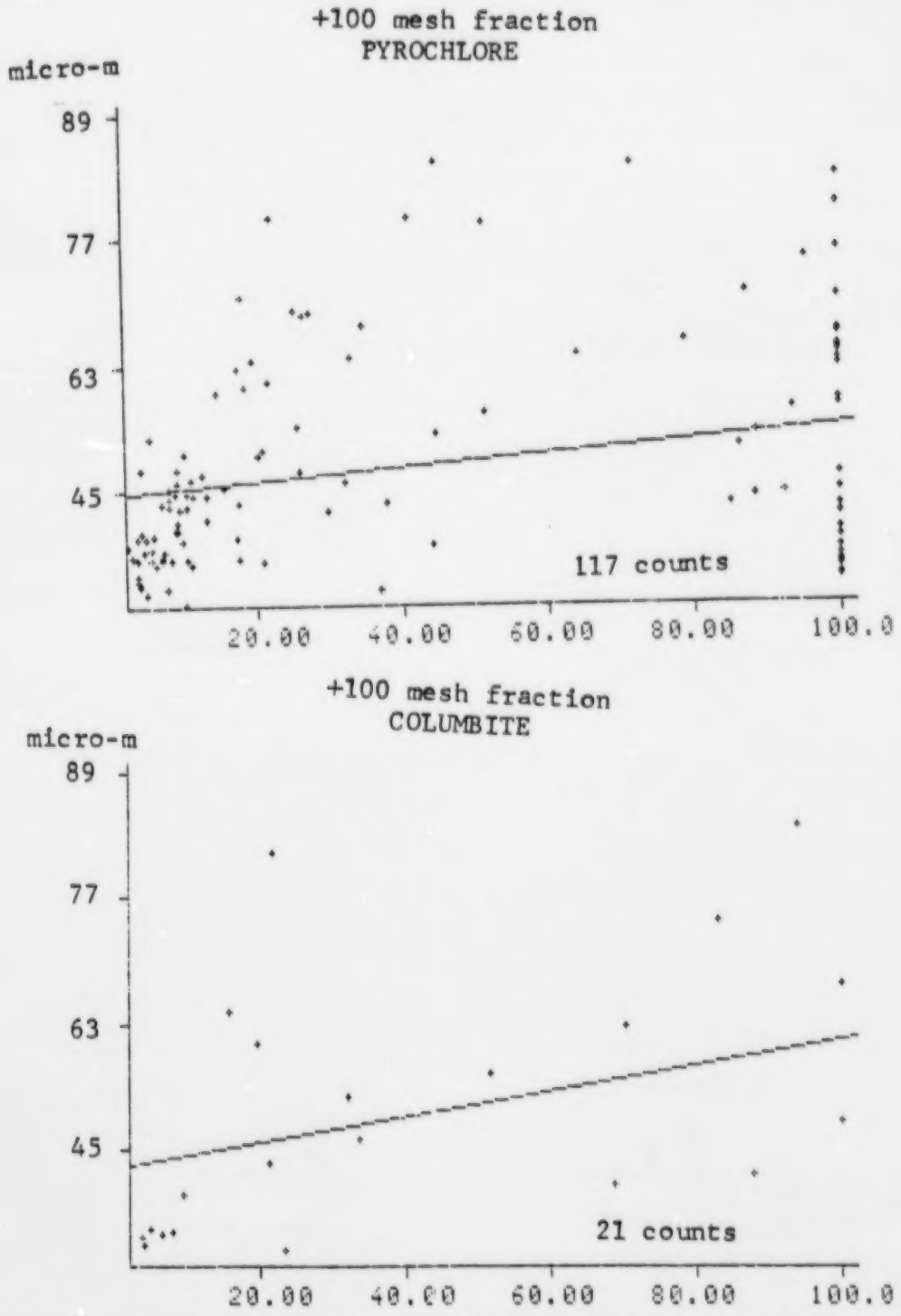
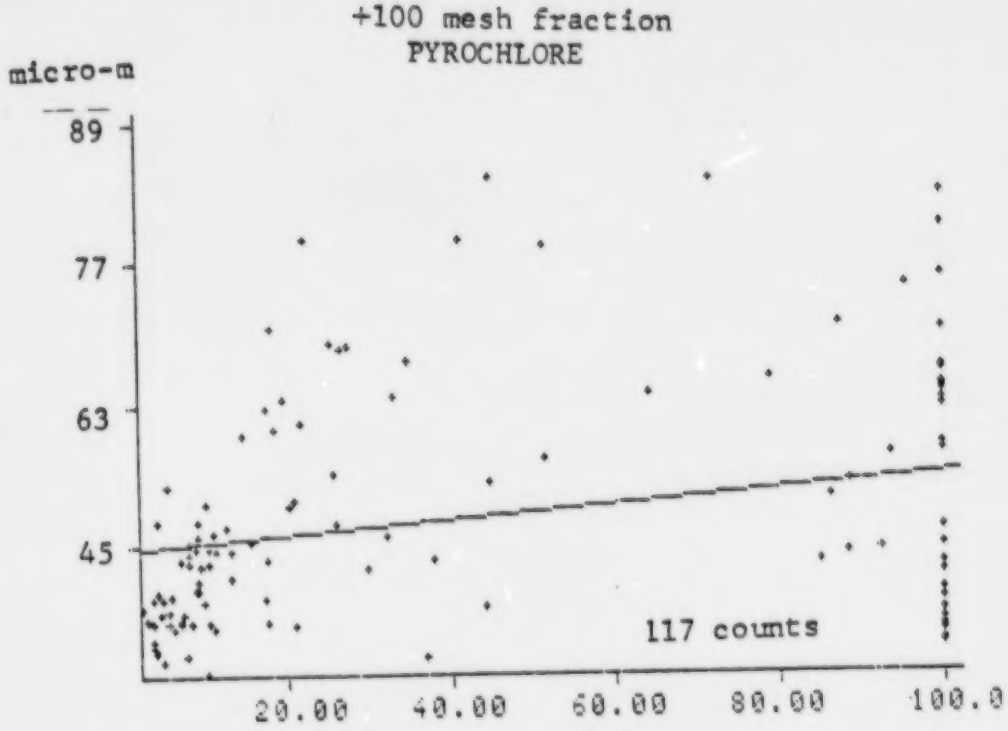


Fig. 13. Scatter diagrams for pyrochlore and columbite in plus 100 mesh fraction of the tailing showing the relationships between the particles that contain various amounts of these minerals and the sizes of the mineral grains in the particles. A regression line was inserted into the diagram by computer.



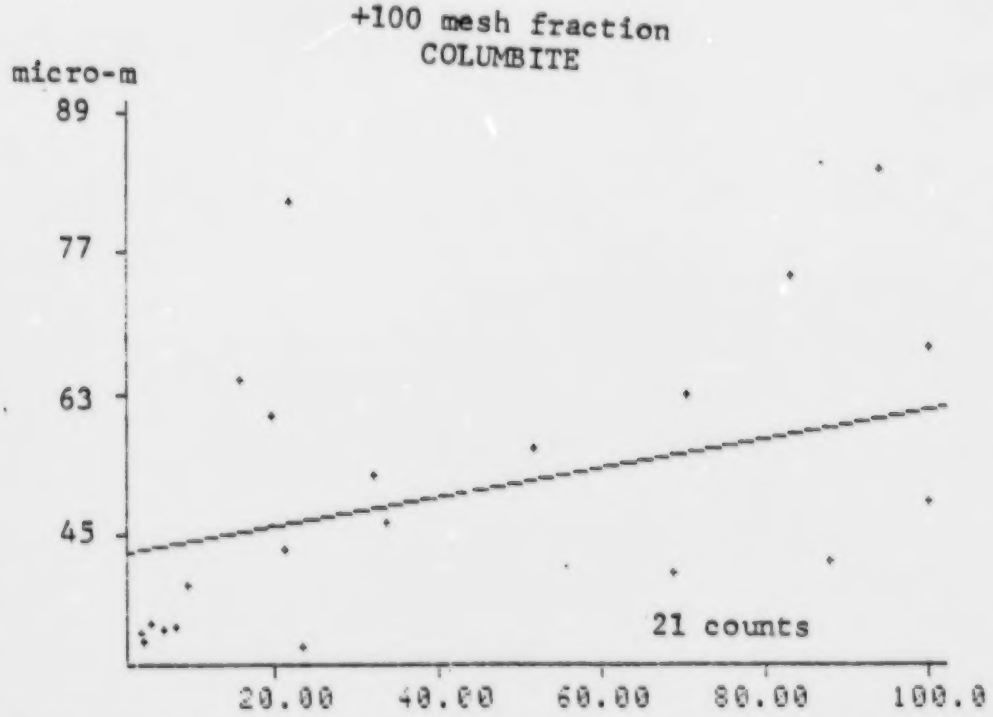
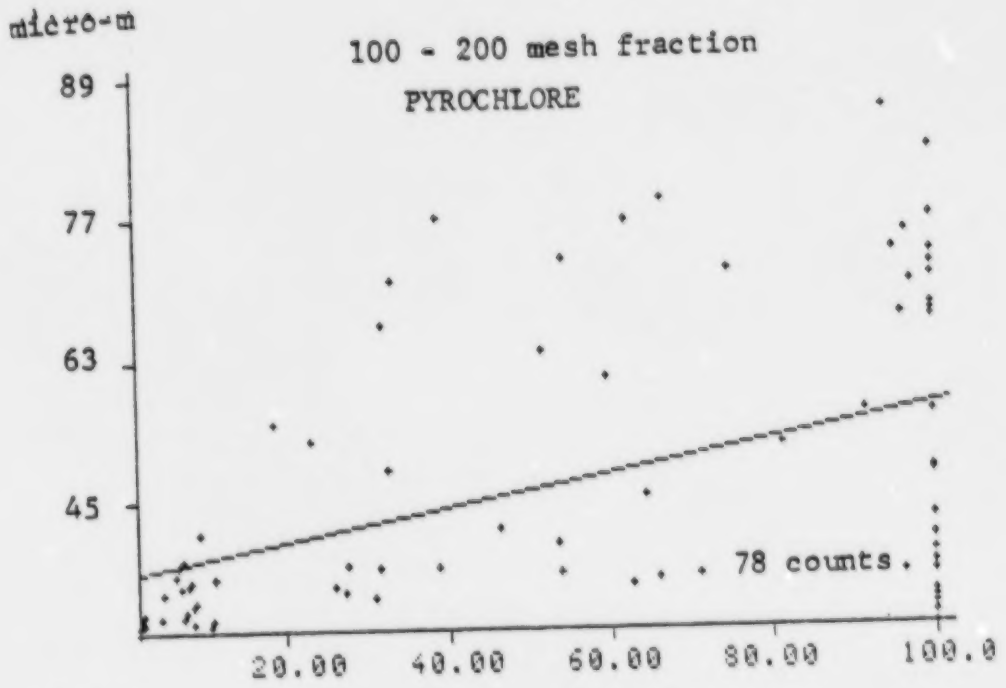


Fig. 13. Scatter diagrams for pyrochlore and columbite in plus 100 mesh fraction of the tailing showing the relationships between the particles that contain various amounts of these minerals and the sizes of the mineral grains in the particles. A regression line was inserted into the diagram by computer.



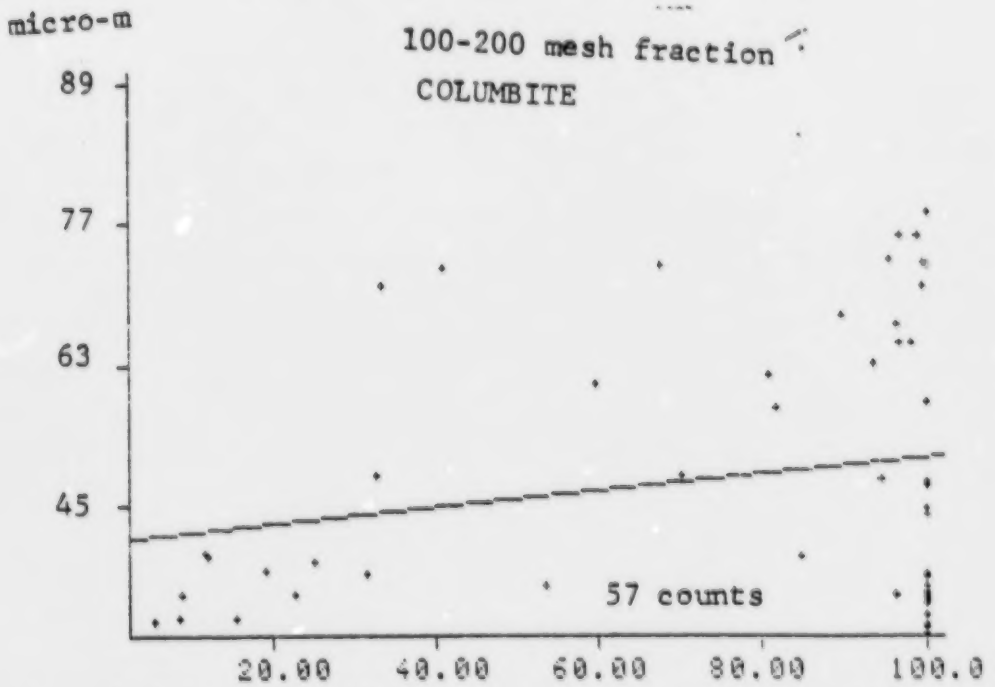


Fig. 14. Scatter diagrams for the pyrochlore and columbite in the 100 to 200 mesh fraction of the tailing showing the relationships between the particles that contain various amounts of the minerals and the sizes of the mineral grains in the particles.

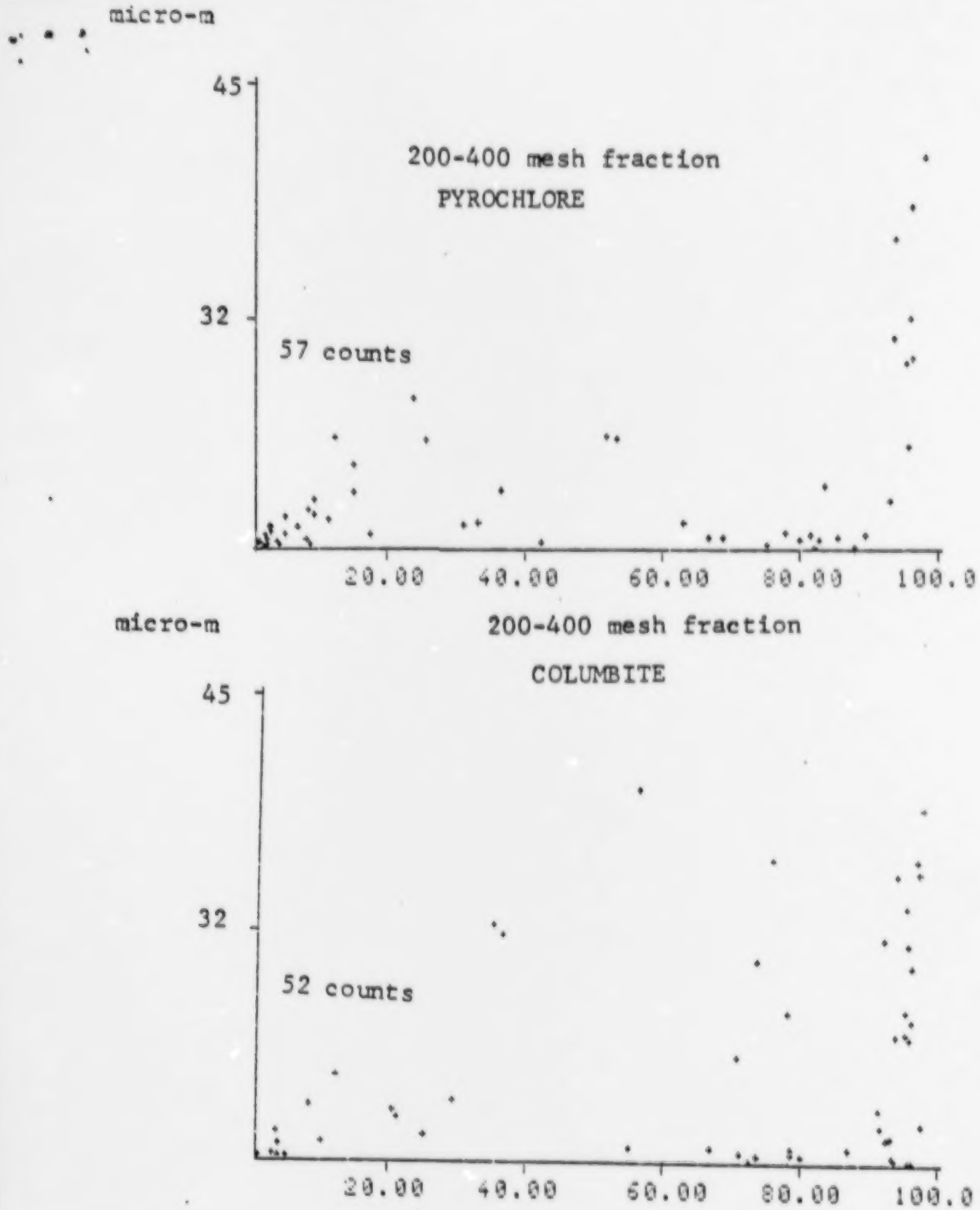


Fig. 15. Scatter diagrams for the pyrochlore and columbite in the 200 to 400 mesh fraction of the tailing showing the relationships between the particles that contain various amounts of the minerals and the sizes of the mineral grains in the particles.

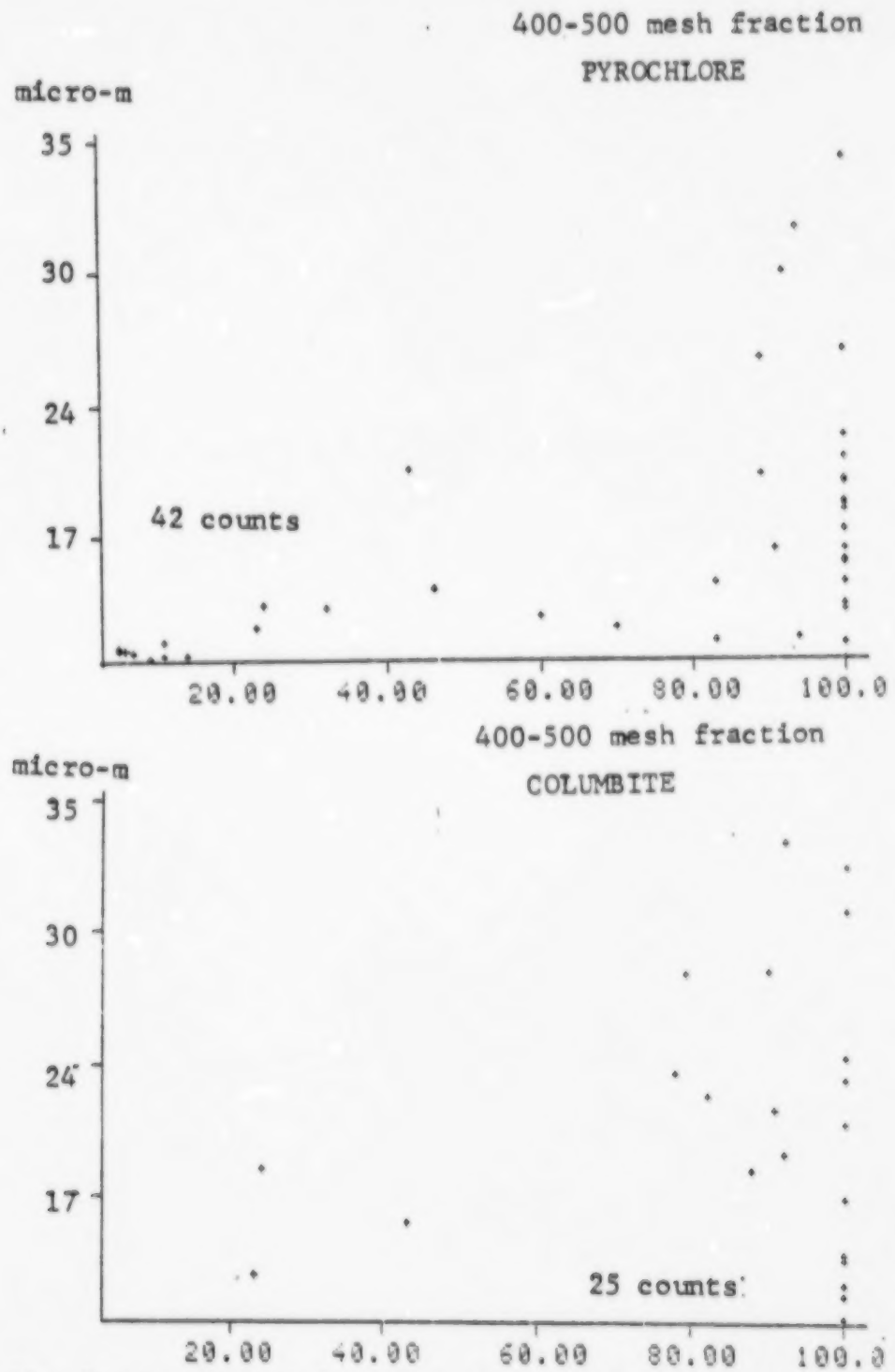


Fig. 16. Scatter diagrams for the pyrochlore and columbite in the 400 to 500 mesh fraction of the tailing showing the relationships between the particles that contain various amounts of the minerals and the sizes of the mineral grains in the particles.

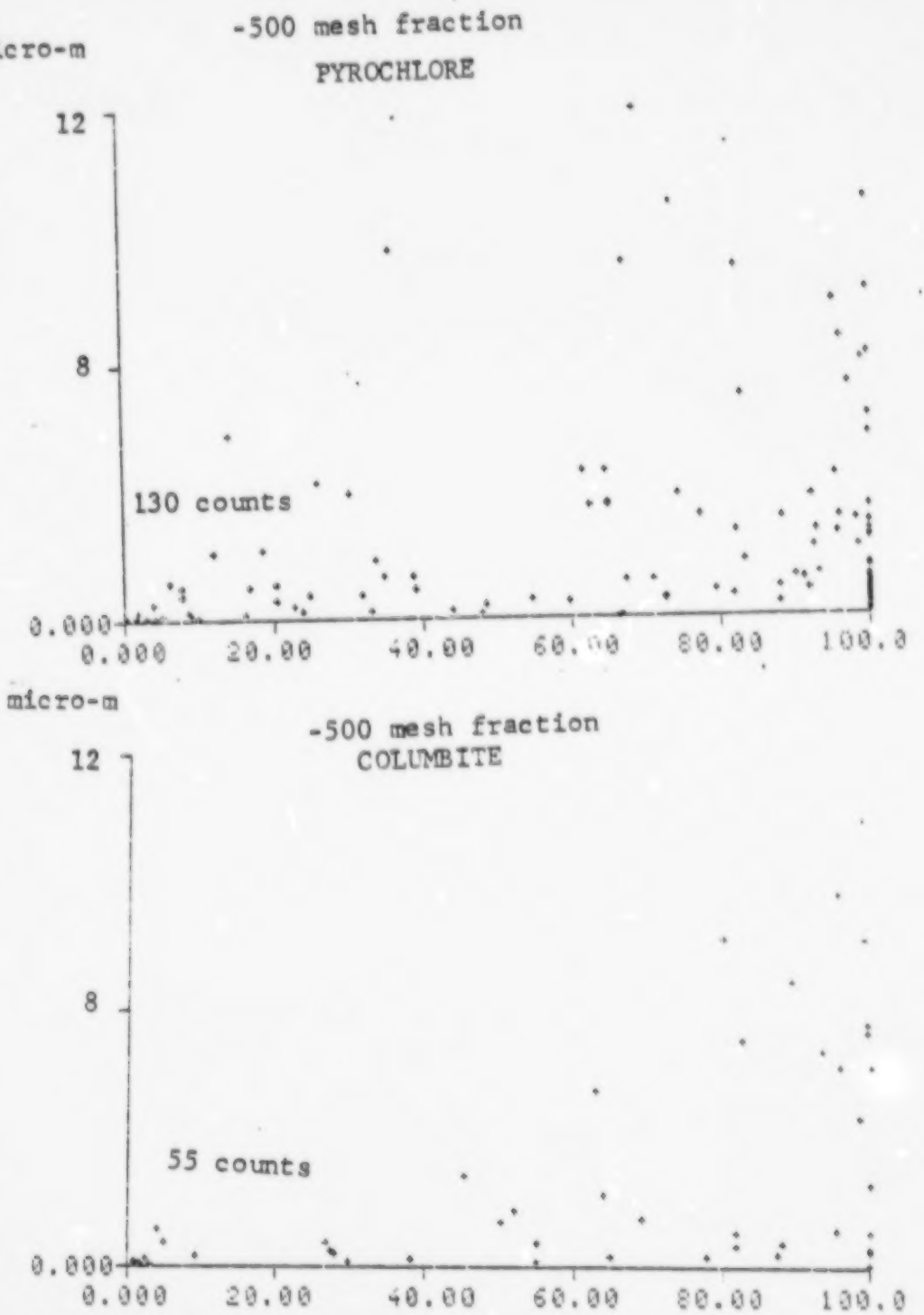


Fig. 17. Scatter diagrams for the pyrochlore and columbite in the minus 500 mesh fraction of the tailing showing the relationships between the particles that contain various amounts of the minerals and the sizes of the mineral grains in the particles.

Table 1. Chemical Compositions

Mineral	Nb_2O_5 wt %	TiO_2 wt %	La_2O_3 wt %	ZrO_2 wt %	FeO wt %	MnO wt %	CaO wt %	Na_2O wt %	ThO_2 wt %	U_3O_8 wt %
Na pyrochlore	65.03	3.64	0.04	1.00	1.05	0.28	15.65	5.90	0.72	0.04
Fe pyrochlore	68.22	3.16	-	-	6.18	-	13.81	3.80	2.15	0.22
columbite	70.11	3.60	0.11	0.10	13.56	2.31	1.13	0.24	0.65	0.09
rutile	13.10	80.9	-	-	5.1	-	-	-	-	-

Table 2. Assay of Pyrochlore Cleaner Tailings

Nb_2O_5 wt %	SiO_2 wt %	Fe (total) wt %	MgO wt %	P_2O_5 wt %	CaO wt %	S wt %
1.62	28.62	17.10	11.14	0.61	6.76	1.91

Table 3. Quantities* of Minerals in Fractions of Concentrate

Fraction (Sieve)	wt % of fraction	Na Pyro. assay %	Fe Pyro. assay %	Ca Pyro. assay %	Columbite assay %	Zircon assay %	Rutile assay %	Rutile assay %	Total
+300	36.9	46.3	70.0	2.4	1.1	8.2	2.2	1.6	
300 +400	41.8	44.9	17.8	9.1	1.1	6.3	6.0	6.6	
-400	1.3								
Combined	100.0	47.1	78.9	3.4	1.9	7.6	3.8	4.3	100.0

Table 4. Semi-quantitative Analyses with EDXA

Mineral	Photo reference	Nb wt%	Ti wt%	Fe wt%	Mn wt%	Ca wt%	Na wt%	Sr wt%	Remarks
Na pyro.		71.7	3.1	0.9*	0.5*	19.5	-	4.4*	
" "		70.5	3.0	1.7	0.6*	16.5	1.6	6.2	
" "		69.5	3.5	1.3	0.7*	15.7	1.6	7.8	
" "	Fig. 1 3	71.7	2.6	1.1	0.6*	16.4	1.5	6.0	
" "	Fig. 1 6	70.7	2.8	1.7	0.8	16.6	1.5	5.8	
" "	Fig. 2 1	70.6	2.9	1.3	0.7*	16.2	1.6	6.6	
" "		72.9	3.0	1.0	0.7*	15.8	1.6	5.0	
" "	Fig. 1 4	72.7	2.5	1.2	0.5*	15.6	1.2	6.0	thorium peak present
Ti pyro.		67.4	4.2	1.8	1.4	17.4	1.2	6.6	
		70.7	3.5	2.0	0.6*	15.2	1.4	6.6	
		70.9	3.8	1.9	0.9	14.8	1.4	6.4	th. peak present
	Fig. 3 2	70.4	3.1	2.2	0.9	14.9	1.4	6.1	th. peak present
	Fig. 1 2	69.5	4.0	0.7	0.5*	16.8	1.6	6.0	
		69.0	4.8	0.9	0.6*	17.3	1.4	6.0	
		69.4	4.2	1.4	0.6*	16.8	1.5	6.1	
		70.7	3.6	1.2	0.6*	16.0	1.3	6.6	
Sr pyro.		69.4	3.5	1.1	1.4	14.8	1.1	8.8	
		68.0	3.1	1.7	1.3	15.5	0.7*	9.7	
	Fig. 1 1	69.5	2.8	1.6	0.7	12.0	1.1	12.3	
	Fig. 4 2	69.4	4.5	1.4	0.6*	16.8	1.3	10.1	
Fe pyro.	Fig. 1 5	69.4	3.3	4.9	1.3	13.9	0.8	6.5	
		68.7	3.3	12.8	4.3	5.3	0.5*	5.2	
		73.6	2.4	5.7	2.3	10.5	0.5*	5.0	
columbite		69.9	2.5	13.1	6.5	2.1	0.5*	5.3	

*
- no peak detected, actual value low or not present.
- Sr peak occurs on shoulder of Nb peak - actual value much lower than reported.
- Na value probably much higher than reported.

Table 5. Classification of Pyrochlore and Columbite in Concentrate

Class	Na Pyro			Fe Pyro			Sr Pyro			All Pyro			Columbite		
	200-400M	+200M	Comb.	200-400M	+200M	Comb.	200-400M	+200M	Comb.	200-400M	+200M	Comb.	200-400M	+200M	Comb.
0- 10	2.3	0.1	0.7	0.2	0.5	0.4	2.3	0.6	1.9	0.0	-	-	33.3	7.5	25.0
10- 20	3.2	1.1	1.8	2.1	1.9	2.0	3.1	2.3	2.8	0.02	0.1	-	23.1	2.4	16.4
20- 30	3.5	0.1	1.2	3.9	3.4	3.7	7.3	1.3	5.7	0.08	0.0	-	8.4	36.7	17.5
30- 40	11.4	3.0	5.7	7.8	5.0	6.3	17.8	11.1	15.8	0.05	0.1	0.1	2.3	33.8	12.6
40- 50	8.2	2.5	4.3	10.3	4.7	7.3	23.7	0.0	17.1	0.02	0.1	0.1	7.5	0.5	5.3
50- 60	12.1	2.2	5.6	8.3	4.8	6.5	20.7	33.4	24.4	0.9	0.1	0.5	1.3	17.4	6.6
60- 70	13.9	4.0	7.2	16.8	20.2	18.5	5.0	40.6	15.0	0.2	0.5	0.4	12.6	0.0	8.5
70- 80	22.9	9.1	13.5	19.6	8.6	13.9	17.6	1.5	13.0	1.1	1.1	1.2	6.7	0.3	4.6
80- 90	21.9	26.8	25.2	23.1	25.9	24.5	-	3.8	1.1	4.6	14.4	10.4	3.1	0.2	2.3
90-100	-	51.2	34.8	7.9	25.2	16.9	2.4	5.4	3.2	93.0	83.6	87.3	1.2	1.2	1.2

Table 6. Quantities of Niobium Bearing Minerals in Tailing

Fraction (Mesh)	wt % of fraction	Quantity (area %)			Distribution %		
		Pyro.	Columbite	High at No.* Minerals	Pyro.	Columbite	High at No.* Minerals
-500	41.28	0.81	0.55	14.5	48.8	36.4	59.3
500-400	12.56	0.44	0.58	7.0	7.7	11.4	8.5
400-200	27.01	0.33	0.82	7.0	10.7	30.0	15.8
200-100	16.12	0.84	0.77	6.3	19.1	19.9	10.1
+100	3.03	1.28	0.19	8.4	13.7	2.3	6.3
Combined	100.00	0.70	0.62	10.1	100.0	100.0	100.0

*Includes pyrochlore, columbite, pyrite, hematite, zircon, rutile, apatite, and are rare earth mineral

Table 7. Classification of Pyrochlore and Columbite in Tailing

Class	Pyrochlore %						Columbite %					
	-500M	500-400M	400-200M	200-100M	+100M	Comb.	-500M	500-400M	400-200M	200-100M	+100M	Comb.
0- 10	1.7	1.8	11.4	6.8	5.5	4.3	1.8	0.0	1.6	0.9	3.9	1.4
10- 20	4.1	1.1	8.6	2.6	6.2	4.3	0.0	0.0	1.2	2.5	6.2	1.0
20- 30	2.7	2.0	7.2	3.1	7.3	3.8	1.0	3.2	2.2	1.2	14.8	2.0
30- 40	8.0	1.1	3.4	11.7	1.5	6.8	0.1	0.0	5.1	5.2	3.9	2.7
40- 50	0.3	5.4	0.3	0.9	3.2	1.2	2.3	1.6	0.0	3.3	0.0	1.7
50- 60	0.4	1.0	6.4	8.8	12.6	4.4	1.5	0.0	4.3	2.8	2.50	2.4
60- 70	17.4	0.8	1.8	9.0	1.6	10.7	5.3	0.0	0.2	3.3	13.8	3.0
70- 80	3.7	0.0	1.1	3.5	6.7	3.5	5.8	9.0	14.3	1.5	12.1	8.0
80- 90	10.0	2.2	4.1	1.6	6.4	6.6	19.8	3.5	0.2	13.3	5.7	10.4
90-100	51.8	84.4	55.8	52.1	49.0	54.4	62.4	82.7	70.8	66.2	37.1	67.4

Table 8. Distribution* of Pyrochlore and Columbite in Tailings

Size Range	Pyrochlore						Columbite					
	-500M	400-500M	200-400M	100-200M	+100M	Total Sample	-500M	400-500M	200-400M	100-200M	+100M	Total Sample
- .8	0.1	0.0	-	-	-	0.1	0.1	-	-	-	-	-
- 1.15	0.5	0.0	-	-	-	0.3	0.4	-	-	-	-	0.2
- 1.6	1.5	0.0	-	-	-	0.7	0.7	-	-	-	-	0.3
- 2.3	3.9	0.0	-	-	-	1.9	2.0	-	-	-	-	0.7
- 3.25	10.2	0.0	-	-	-	5.0	5.1	-	-	-	-	1.9
- 4.6	8.8	0.3	0.2	-	-	4.3	3.8	-	-	-	-	1.4
- 6.5	24.3	1.4	1.5	-	-	12.1	5.6	0.4	0.6	-	-	2.2
- 9.2	28.0	3.0	6.8	-	-	14.6	41.9	0.5	1.5	-	-	15.8
- 13	22.7	7.4	8.7	0.1	-	12.6	15.8	3.2	1.8	-	-	6.7
- 18.5	-	16.4	9.3	1.1	-	2.5	0.0	6.6	4.1	0.5	-	2.1
- 26	-	33.0	22.0	3.6	0.7	5.7	24.6	28.6	11.5	1.4	2.0	16.0
- 37	-	38.5	31.3	11.0	3.8	8.9	-	47.3	33.7	10.9	2.2	17.7
- 52	-	-	20.2	9.5	8.4	5.1	-	13.4	38.5	9.5	7.5	15.1
- 74	-	-	-	46.5	14.1	10.8	-	-	8.3	41.3	17.6	11.1
-104	-	-	-	28.1	18.2	7.9	-	-	-	28.9	29.2	6.4
-147	-	-	-	-	17.0	2.3	-	-	-	7.6	41.5	2.5
-208	-	-	-	-	32.5	4.5	-	-	-	-	-	0.0
+208	-	-	-	-	5.3	0.7	-	-	-	-	-	-
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

*includes free grains and inclusions